Radiation Physics Note 48

NEUTRON CALIBRATION TESTS OF FERMILAB RADIATION DETECTORS

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I. INTRODUCTION

Prompted by Recommendation 5 of the July, 1984 DOE Health Physics Appraisal, we have undertaken a study of the neutron response of some standard Fermilab radiation detectors that are generally calibrated only with γ-rays. This note presents a summary of the methods used and the results of these tests.

II. EXPERIMENTAL METHOD

Several types of instruments are in use at Fermilab to monitor the dose rate from ionizing radiation. Among these instruments are Fermilab-designed ionization-chamber area monitors (Chipmunks and Scarecrows) and commercially available instruments (the HPI 1010* and the TEIR†) that are usually calibrated only with γ-ray sources by the Instrument Maintenance and Calibration Group (IMAC), although they are used in areas where neutrons may also contribute to the dose. Details of the instruments designs are found in the Appendix. The measurements described below were made to ensure that these instruments adequately respond to neutrons, as well as γ-rays. All the instruments tested were taken "off-the-shelf" from IMAC, after having been calibrated on the IMAC source calibration table (WH-7E).

*-Health Physics Instruments, Inc.
†-REM, Inc. (chamber only)

A. Outdoor Tests

A test fixture was assembled outdoors at Site 68 to minimize the contribution from scattered neutrons. It consisted of two six-foot step ladders joined near the top with two eight-foot aluminum angles to form a light weight, low mass stand for the detectors. The source-to-detector distance of 2 meters was chosen to ensure compliance with the ANSI-recommended minimum distance of seven times the maximum detector dimension. Each detector to be tested was allowed to stabilize for at least four hours at ambient temperature. A set of measurements consisted of:

1) a background measurement (check-source included)

2) a ^{137}Cs γ-ray measurement (source 137-3.5-1)

3) a ^{238}PuBe neutron measurement (source 238-7.2-1)

The ^{137}Cs γ-ray measurements were done to check instrument calibrations just prior to neutron measurements. The digital outputs (proportional to absorbed dose) from the Chipmunks and Scarecrows were accumulated for 1000 seconds in a scaler/timer. The HPI 1010 and TEIR, which have no digital output, were tested by integrating the dose rate for a preselected time and visually reading the instrument meter face. The doses from each detector were then compared to what was expected from the respective sources.

B. Indoor Tests

A similar set of measurements were made on the second floor (S.E.) of Site 68 to assess the contribution from room-scattered neutrons. This room is sometimes used for calibrations and test exposures with various sources. As with the outdoor measurements, the source-to-detector distance was 2 meters, with the detector and source approximately centered in the room and 4 feet above the floor.

C. Source Strengths

The γ-ray source (137-3.5-1) was NBS calibrated on September 20, 1982. The reported dose rate was 1.56 ± .014 mr/hr at 1 meter distance. Corrected for decay and distance of the present measurements, the dose rate was 0.372 ± .003 mr/hr.

The dose rate due to neutrons can be calculated by using the neutron spectrum for the ^{238}PuBe source and a set of fluence-to-dose conversion factors for mono-energetic neutrons[1] to arrive at a conversion factor appropriate for this particular type of source. Such a calibration factor has been derived by Hofert, et. al.,[2] who found a value of 4.3×10^{-6} mrads/n/cm^2. Using this factor and our 2 meter irradiation distance, the decay-corrected calculated dose rate due to neutrons is 0.54 mrads/hr.

In order to extract a measured neutron dose rate, the data must be corrected for the γ-component of the ^{238}PuBe source. The source manufacturer[3] quotes a γ-contribution of 0.13 mr/hr/Ci at 1 meter distance. This results in a 0.18 mr/hr γ-dose rate for our 5.55 Ci ^{238}PuBe source at 2 meters.

III. RESULTS

A. γ-ray Tests

The results of the γ-ray tests are shown in Table 1. "Old" and "New" refers to the type of ionization chamber installed in the Chipmunk and Scarecrow (see Appendix). Note that background measurements were made with the standard check sources in place for Chipmunks and Scarecrows. All four of those detectors gave consistent γ-dose results during the outdoor measurements, but showed a systematic $\sim$9% increase over the expected dose rate of $0.372 \pm .003$ mr/hr. The TEIR and HPI 1010 were $\sim$5.6% and 3% low, respectively. Some systematic deviation may be explained by the 3.7% relative calibration uncertainty between the IMAC calibration sources and the source used in the present tests. Additional factors affecting the uncertainty include finite-size effects and scatter from the IMAC γ-source calibration table. Finite-size effects are more important for the larger Chipmunks and Scarecrows than for the TEIR or HPI 1010 and would result in deviations in the observed direction. The indoor γ-source measurements are slightly higher still, due probably to additional scatter that was not present outdoors. However, this increase is not observed consistently for all the detectors tested (cf. New Chipmunk and New Scarecrow).

Because the systematic uncertainties associated with the outdoor γ-ray measurements at Site 68 were considered to be less than those for the standard IMAC calibrations, the outdoor measurements were used as the primary calibrations of the detectors. Thus, calibration correction factors were computed for each detector. They are simply 0.372 mr/hr divided by the measured outdoor γ-ray dose rate. These are given in the last column of Table 1 and have been used to re-normalize the measured neutron dose rates shown in Table 2.

B. Neutron Tests

The results of the neutron tests are given in Table 2. The numbers in parentheses in columns 5 and 8 are the measured neutron dose rates, corrected for background, γ-contribution from the ^{238}PuBe source, and re-normalized by the calibration correction factors discussed above. These numbers should be compared to the calculated dose rate of 0.54 mrad/hr. Agreement to 10% or better is obtained for all Chipmunks and Scarecrows tested. The TEIR over-responds by about 21% while the HPI 1010 indicates the largest discrepancy between measured and calculated values (an under-response of $\sim$40%).

The major systematic uncertainties in comparing measured neutron dose to expected dose involve the fluence-to-dose conversion factor and the γ-ray dose from the PuBe source. Fluence-to-dose conversion factors of 4.0 to 4.7 x 10^{-6} mrad/n/cm^2 appear in the literature.[2,4,5] The chosen value of 4.30 x 10^{-6} lies near the mid-point of this range. Values for the γ-ray dose range from 8% to 25%[6,7] of the total dose from the source. In computing the numbers in Table 2, the source manufacturer's quoted γ-ray dose, which corresponds to the 25%

contribution, was assumed. Not only does use of the manufacturer's γ-dose give the best agreement with the calculated neutron dose, but it represents the most conservative choice from a safety standpoint. Use of a smaller assumed γ-ray contribution would result in a higher measured neutron dose. In that case, one would infer that the detectors (with the exception of the HPI 1010) were over-responding to neutrons.

The indoor measurements at Site 68 are typically $\sim$20% higher than the outdoor ones (Table 2, column 9), presumably due to room-scattering. This amount of scatter is consistent with expectations based on measurements at other neutron irradiation facilities.[8] The "Old" Scarecrow shows a 31% enhancement, which may be due to the construction of the chamber in this detector. It is the only one of the four area monitor ionization chambers which has bare walls.

The only detector which appears to have a problem at the present time is the HPI 1010. Of the 6 detector types tested it is the only one operating in a low pressure gas-proportional mode. Besides its apparent under-response of 40%, it showed no enhancement of the dose for the indoor measurements.

IV. CONCLUSIONS

Fermilab radiation monitors that are usually calibrated only with γ-ray sources were found to respond adequately (with one exception) to neutrons. Good agreement between measured and calculated neutron dose rates from a PuBe source was obtained, once corrections for background and γ-rays from the source were applied. The one exception was the HPI 1010 portable gas-filled proportional chamber (of which there are four on-site). It exhibited a 40% under-response to neutrons and was apparently insensitive to the room-scattered neutron component during an indoor measurement. The cause of the anomalous reading for this instrument is not understood at the present time.

TABLE 1. γ-ray Test Results

			Outdoor $\left(\frac{mrad}{hr}\right)$			Indoor $\left(\frac{mrad}{hr}\right)$			
Instrument	Serial No.	Bkg.	Gross	Net	Bkg.	Gross	Net	Ratio $\frac{\text{Indoor}}{\text{Outdoor}}$	Calibration Correction Factor
Old Chipmunk	90	.122	.533	.411	.126	.544	.418	1.02	.905
New Chipmunk	173	.148	.549	.401	.167	.566	.399	1.00	.928
Old Scarecrow	28	25.47	25.88	.41	25.38	25.81	.43	1.05	.907
New Scarecrow	33	24.68	25.09	.41	24.71	25.11	.40	0.98	.907
TEIR	3	.035	.386	.351	.025	.394	.369	1.05	1.06
HPI 1010	2	.0107	.372	.361	.016	.402	.386	1.07	1.03

TABLE 2. Neutron Test Results

Instrument	Serial No.	Outdoor $\left(\frac{mrad}{hr}\right)$ Bkg.	Outdoor $\left(\frac{mrad}{hr}\right)$ Gross	Outdoor $\left(\frac{mrad}{hr}\right)$ Net*†	Indoor $\left(\frac{mrad}{hr}\right)$ Bkg.	Indoor $\left(\frac{mrad}{hr}\right)$ Gross	Indoor $\left(\frac{mrad}{hr}\right)$ Net*†	Ratio $\frac{Indoor}{Outdoor}$
Old Chipmunk	90	.122	.967	.765 (.585)	.126	1.09	.872 (.692)	1.18
New Chipmunk	173	.148	.868	.668 (.488)	.167	.994	.767 (.587)	1.20
Old Scarecrow	28	25.47	26.24	.70 (.52)	25.38	26.33	.86 (.68)	1.31
New Scarecrow	33	24.68	25.43	.68 (.50)	24.71	25.56	.77 (.59)	1.18
TEIR	3	.035	.822	.834 (.654)	.025	.915	.943 (.763)	1.17
HPI 1010	2	.0107	.501	.505 (.325)	.016	.498	.496 (.316)	.97

†Numbers not in parentheses result from applying the calibration correction factors in Table 1.
*Numbers in parentheses include subtraction of 0.18 mrad/hr γ-contribution.

REFERENCES

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2. Hofert, M. and Ch. Raffnsoe. 1980. Nucl. Inst. and Meth. 176(443)
3. Monsanto Research Corporation, Dayton, Ohio.
4. Nachtigall, D. 1967. Health Physics. 13(213).
5. Awschalom, M., T. Borak and H. Howe. 1971. Fermilab TM-291 4.
6. Lawrence, D. C. 1962. Health Physics. 7(179).
7. Monsanto Technical Source Notes, pg. 19.
8. Schwartz, R. B. 1984. Personnel Radiation Dosimetry Symposium, Knoxville, TN.

APPENDIX

Detector Descriptions

Old Chipmunk - A high-pressure gas-filled ionization chamber designed by Fermilab and built by LND, Inc. with 4 mm thick walls of tissue-equivalent plastic. The fill gas is 150 PSIG of ethane. The chamber is enclosed in a protective box which contains a sensitive electrometer and associated electronics to measure the current output and convert it to dose-equivalent rate. Switch-selectable Quality Factors of 1, 2.5 or 5 are available.

New Chipmunk - Similar to Old Chipmunk except for use of a phenolic-lined ionization chamber, filled with propane gas at atmospheric pressure and an electrometer encased in a sealed container.

Old Scarecrow - A high-pressure ionization chamber with bare (stainless steel) walls filled with 150 PSIG of ethane gas. Similar to electrometer for Old Chipmunk but with a fixed Quality Factor of 4 and capability to measure dose rates 100 times higher (up to 10 Rem/hr).

New Scarecrow - Same electronics as Old Scarecrow, but with phenolic-lined chamber and electrometer enclosure identical to the ones in the New Chipmunk.

TEIR - Tissue Equivalent Integrating Ratemeter. A commercially available Tissue Equivalent ion chamber like that supplied with the REM, Inc. model 112, but interfaced to Fermilab-designed electronics. The ion-chamber is filled with 18 PSIG ethane gas and has a nearly parallel plate geometry.

HPI 1010 - Commercially available survey meter consisting of a gas-filled multiplying ion chamber and associated electronics. The chamber is filled with 100 mm Hg of TE gas inside a TE plastic chamber.